ON INFRASOUND DETECTION AND LOCATION STRATEGIES

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ABSTRACT

Routine processing of infrasound array data has been ongoing at relatively few locations during the recent past, and at these locations there has been little to no processing of data from large infrasound networks. As more infrasound monitoring stations become operational, data from them will take on more importance, especially with regard to automated processing routines. We discuss various ideas on detection and location strategies based on our operational experience and input from infrasound researchers. This presentation is directed toward stimulating the discussion about the best approaches to the infrasound data-processing task. This discussion applies to the monitoring task, and it should be noted that this is not the same as the research task. A good research program improves the monitoring function.

Aspects of existing automated processing, other approaches that can aid in the identification of interesting events, and simple criteria that can screen out uninteresting events are considered. The value of wide band processing for sparse arrays is discussed. Implementation of standard location techniques for infrasound monitoring is considered using simple travel-time data. Guidelines for comparison of different approaches are discussed and illustrated with data from bolides and earthquakes.

OBJECTIVE

The last US infrasound network was almost entirely closed out by about 1974 after 20 years of service detecting atmospheric nuclear explosions. In the mid 1970s, digital signal processing was just beginning to be used in a variety of disciplines, and infrasound benefitted only a little from this new processing. Routine processing of infrasound data, prior to 1998, was or had been done at only a few locations, including: Los Alamos National Laboratory (LANL); the National Oceanographic and Atmospheric Administration in Boulder CO; University of Alaska, Fairbanks AK; and Columbia University NY. Our objective here is to stimulate thought and discussion about signal processing applicable for analysis of the developing infrasound network of the International Monitoring System. The presentation will draw on our experience and will be an overview rather than an exhaustive analysis.

RESEARCH ACCOMPLISHED

As a waveform technology, infrasound can benefit from some of the existing processing infrastructure developed during the long monitoring period of seismic research. After all, there is similarity in frequency content and sampling rates; many concepts apply straightaway. But there are differences as well. In traditional infrasound work, little use is made of power detectors because, in part, the wind backgrounds can be quite variable. Rather, because the signals from distant sources are usually well correlated, cross-correlation detectors are far more common in infrasound and acoustic processing. LANL found that the algorithm developed by Young and Hoyle (1975) to be highly valuable in their work from 1983 to the present. Of course one might work with an F detector, rather than cross-correlation, where, for ideal conditions, the F statistic is related to the correlation coefficient, C, as, $F = n C /(1-C) + 1$, where n is the number of sensors. Normalized cross-correlation is bounded, 0 to 1, while the F statistic is unbounded.

The processor discussed by Young and Hoyle (1975) has some differences from traditional FK processing, and they describe their approach as frequency slowness $S(\omega)$. One point they present is that for wide-band non-dispersive signals, the $S(\omega)$ processor mitigates against side lobe alignment in different frequency planes and reduces their importance. Ferguson (1999) and Katz (2001) also discuss this point from a different perspective but show the value of wide-band processing in many cases. Below we show traditional FK results for some data from the four-element LANL array at the Nevada Test Site for a correlated signal. The strongest values are deep red with the peak at (x=8, y=23). Other strong cells are apparent over the 40 x 40 FK plane.

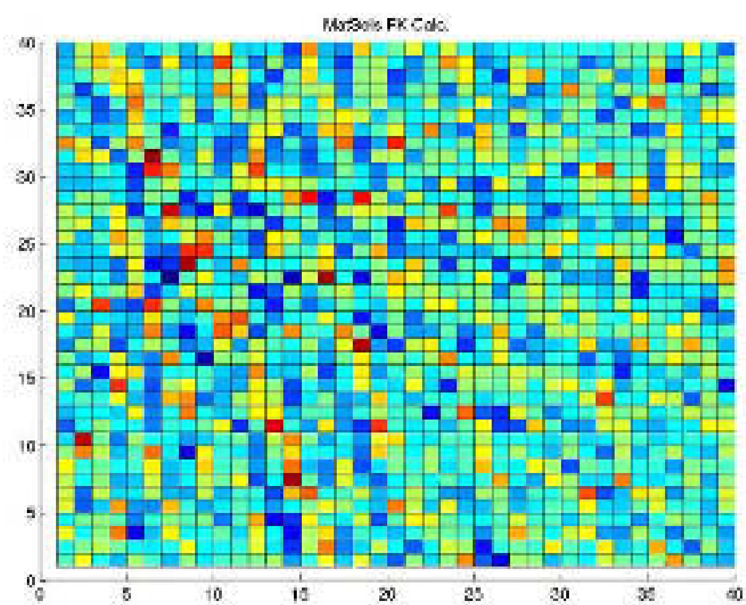

Figure 1. Traditional FK results for some data from the four-element LANL array at the Nevada Test Site for a correlated signal

Figure 2 gives the equivalent result for the same data segment computed with the S(ω) correlation processor. Here the peak is well defined at (8,24) and is clearly the peak value with no competition from other cells. The same window size and passband were used in both cases, and the processing was done with MatSeis.

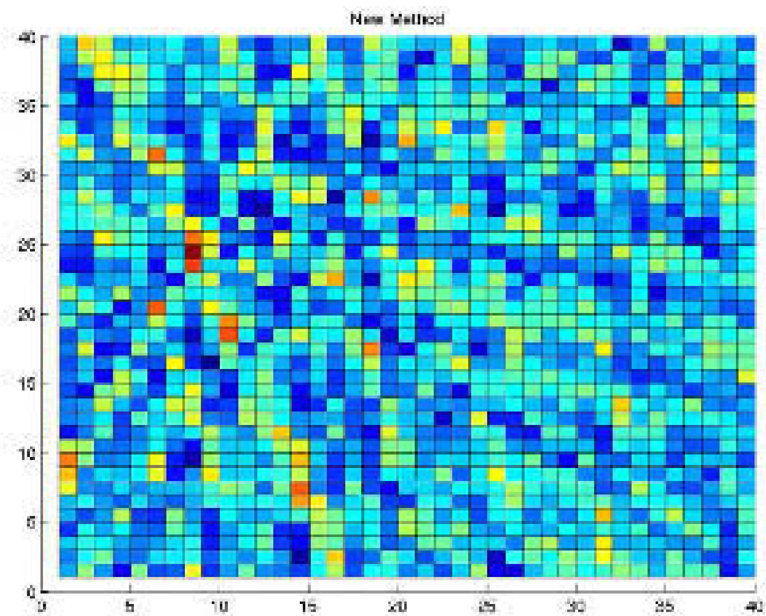

Figure 2. Equivalent result (to that in Fig. 1) for the same data segment computed with the S(ω) correlation processor.

The FK results use the FK tool in MatSeis, and the correlation slowness processing was done with Infra_tool. The results above for S(ω) processing with four elements indicate that the alias problem, with four elements, may not be as serious as first thought. However, there are still good reasons that added elements are needed for improved performance. Added elements provide better array gain as well as redundancy against sensor loss. They will enable better broadband response. In recent work we found another example of how added elements can aid the detection capability.

We recently processed data from DLIAR and LSAR for the shuttle launch of 5 June 2002, expected at around 23:50 UT. LSAR is a smaller baseline array sitting inside the prototype DLIAR array. Spring and summer shuttle launches have been detected by DLIAR, but in this case, as displayed in the figure to the right, DLIAR got very weak correlation, albeit with localization of azimuth and trace velocities. The data were processed with MatSeis and Infra_Tool, and the figure is part of the Infra_Tool Graphical User Interface (GUI) display. From the top, the panels display correlation, trace velocity, azimuth and one channel of data. Twenty-second windows were used with a band pass of 1.0 to 4.0 Hz. The LSAR results show much better correlation, azimuth and trace velocity trends, as is obvious in the next panel. This is an extreme case of the loss of correlation over the larger baseline of the DLIAR (~1.2 km) array as compared to the small baseline (~0.2 km) of the LSAR array. In looking at numerous cases of the same signal on both arrays, we often find a loss of 0.15 to 0.20 units in normalized cross-correlation values due to larger

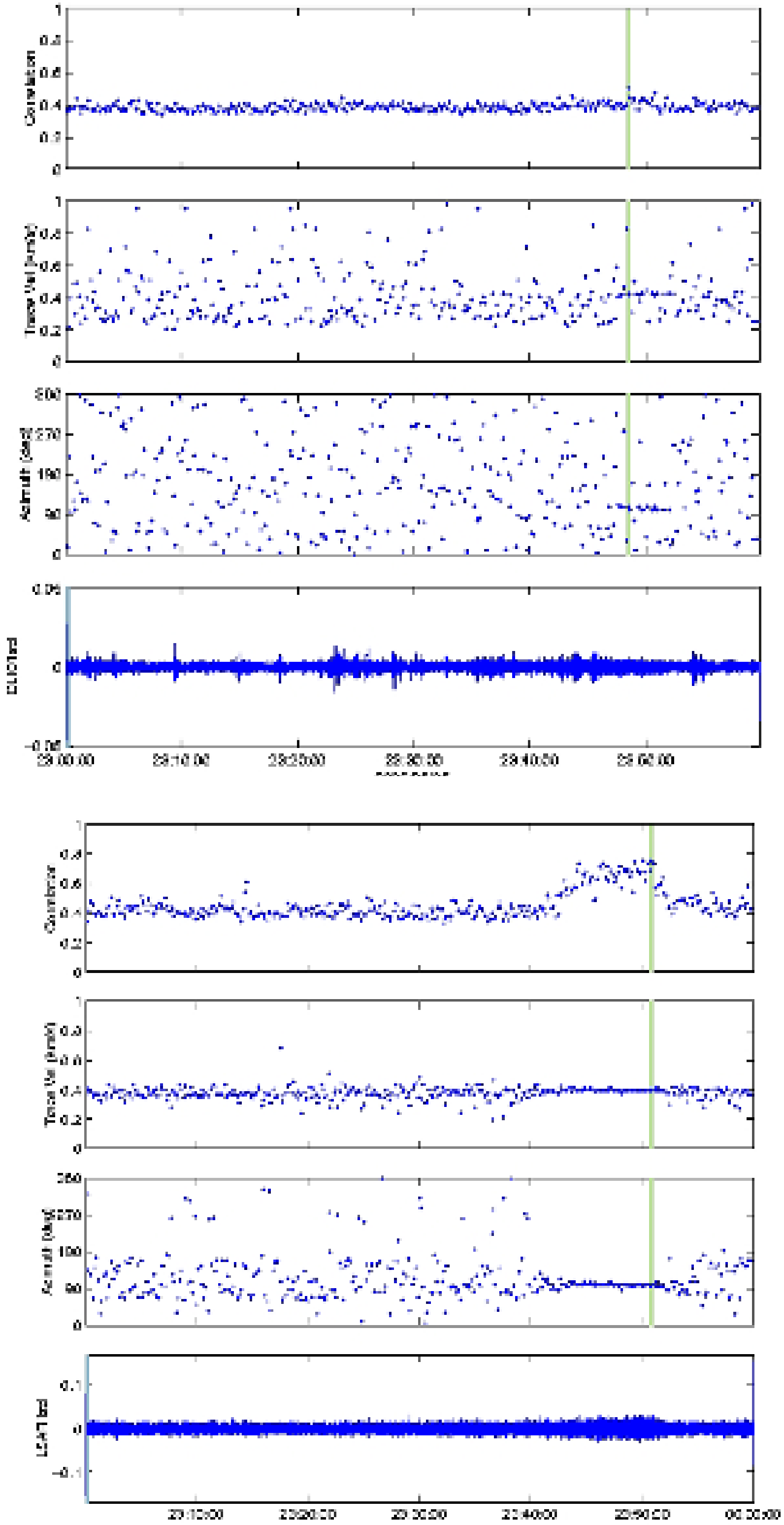

Figure 3. Data from DLIAR (top) and LSAR (bottom) for the shuttle launch of 5 June 2002

baseline. Another example of the correlation loss is given by the DLIAR and LSAR results for a California earthquake on 22 February 2002. Both arrays had good results with the azimuth for DLIAR coming out at 245.9 degrees and that for LSAR at 244.5 degrees. The peak cross-correlation for DLIAR was 0.718 and that for LSAR was 0.944. We are beginning to look again at common DLIAR and LSAR signals now that LSAR has been restored after the Cerro Grande fire.

One could envision a detector based upon the type of processing used in Infra_Tool wherein one would look for constant azimuth signals having some correlation above a threshold and duration longer than some minimum. These results could then be passed onto a global association scheme combining other infrasound stations as well as seismic and hydroacoustic stations.

One of the biggest differences between seismic and infrasound analysis occurs because the atmosphere is dynamic on a variety of time scales, and the solid earth is relatively static. Thus concepts such as travel times with really small variations, on teleseismic distances, are not possible in the atmospheric domain. Location uncertainty in atmospheric acoustics will be larger than in seismic because the travel times will have larger variation, due to the influence of winds. Nevertheless, some average properties of propagation are quite reliable. In the older monitoring period, the main acoustic arrival was associated with energy that arrived with an average travel velocity of 0.290 km/s $\pm$ 0.015 km/s for favorable propagation conditions. In a ray-acoustic picture, this condition represented energy refracted from altitudes of around 50 km and was referred to as a stratospheric return. Higher altitude refractions would, often, show lower average travel velocities of approximatey 0.25 km/s. With atmospheric travel-time variations, locations using only timing would have rather large areas of uncertainty. But because infrasound signals are well correlated, quite good bearings, back azimuths, can be derived, and for two stations, intersecting back azimuths give an estimate of location and distance. With these in hand, one can begin to identify parts of the waveform associated with specific atmospheric phases. Then, among two or more stations, one could examine the results for consistency. Ray-mode theory can aid in location by confirming, if some atmospheric data are available from models or observations, and by showing if signals from the intersection of two or more bearings really can get signals to the stations.

Another difference between infrasound and seismic monitoring is that infrasound uses timings from peak correlation whereas seismic uses first arrival (or onset) time for location. Some infrasound signals emerge slowly out of the background, making onset difficult to determine. Peak correlation can easily be found and the timing can be taken as the time of the middle of the processing window in which correlation peaks. At LANL we have determined this to be an effective approach.

The roles of research and monitoring need to be kept in mind and their differences understood. Analysis for research purposes will be different from that for monitoring. For example, very short impulsive signals are of research interest but can probably be ignored in monitoring as being due to small local events. Events with varying azimuth may be of research value but are not signals from point explosions and thus of little monitoring interest. Over time, results from the research arena will improve the monitoring capability making it more effective. Indeed, it will be the targets of opportunity, cultural and natural, that will provide the events around which the processing can be tested and improved. Both aspects need to be pursued to ensure that the processing is of the highest quality and that signals of interest are not missed.

In comparing results from different tools, one must be careful to be sure that processing parameters are, to the extent possible, the same, or as similar as they can be. A difference in azimuth of five or six degrees may or may not be a real difference. As the processing of infrasound data in the network matures, various schemes will be compared and discussed. We need to be careful to make the comparisons as meaningful as possible.

CONCLUSION

This short contribution has discussed some aspects of infrasound processing based largely on the operational experience at LANL. It has been our desire to stimulate thought and discussion

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